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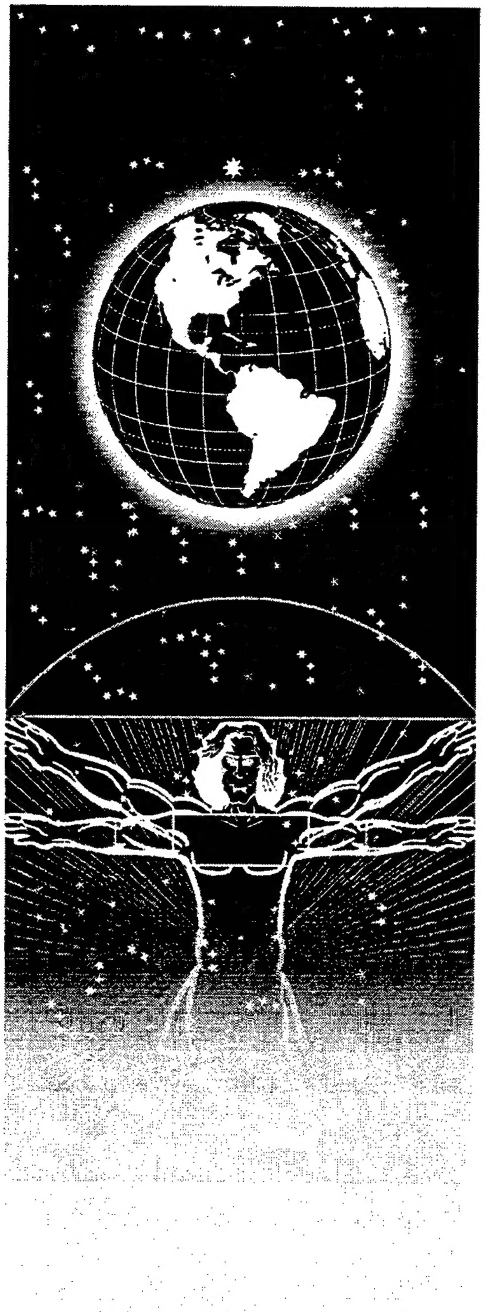

UNITED STATES AIR FORCE
SCHOOL OF AEROSPACE MEDICINE

Submaximal Aerobic Fitness Evaluation

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13. ABSTRACT ***(Maximum 200 words)***

Phase 1A: Twenty-five healthy males, 18 to 30 years of age, completed this study to cross-validate the Banister-Legge (B-L) submaximal cycle ergometry test. The B-L nomogram for untrained and trained subjects and the USAF CE significantly underestimated the measured VO_{2max}. The B-L nomogram was not recommended as a protocol for use by the USAF. Phase 1B: Fifty-eight males and 61 females, 18 to 48 years of age, completed this study to develop new submaximal cycle ergometer protocols and prediction equations to estimate VO_{2max}. Ramp ® and ramp to steady-state (RSS) protocols, six prediction equations for men, and three prediction equations for women were developed. Phase 2: Thirty-one males and 36 females, 18 to 40 years of age, completed this study comparing the 1-mile walk and USAF CE test for estimating VO_{2max}. There were no significant differences between the VO_{2max} estimated by these tests and the measured VO_{2max}. A subset of this population (17 males and 20 females) also completed R and RSS tests. There were no significant differences between the measured and estimated VO_{2max} for the 1-mile walk, the USAF CE, the six new equations for men, and one of three new equations for women.

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Summary

The United States Air Force (USAF) uses a submaximal cycle ergometer test (CE) modeled after the Åstrand and Ryhming protocol (1,2) to assess the aerobic fitness level of its employees. The USAF CE protocol consists of warm-up, power output progression, steady-state, and cool-down phases. The heart rate (HR) and power output at the end of the steady-state are used to generate an estimated VO_{2max} using an algorithm developed by Dr. Loren Myrhe (20).

Shortcomings of this protocol have been identified including: a higher than desired standard error of estimate (SEE) when predicting VO_{2max} and an excessive number of invalid assessments (6,22). The purpose of this project was to find or develop an exercise test protocol that would improve the accuracy of estimating VO_{2max} and reduce the number of invalid tests.

There were two phases to this project. Phase 1 included the assessment of the Banister-Legge (B-L) protocol (18) for estimating VO_{2max} and the initial development of a submaximal CE protocol(s) and equations for estimating VO_{2max}. Phase 2 included the assessment of the Kline et al. (17) 1-mile walk for estimating VO_{2max} and a preliminary cross-validation of the new CE protocols developed in Phase 1.

The following conclusions were made from the studies conducted. 1) The B-L protocol is no more accurate than other protocols and has other problems that make it unsuitable for use by the USAF. 2) The new ramp and ramp to steady-state protocols and equations developed are at least as accurate as the current USAF CE, and their use will likely result in fewer invalid tests. These new protocols and equations should be evaluated in a full scale cross-validation study. 3) The Kline et al. (17) 1-mile walk is at least as accurate as the new equations or the USAF CE. Further evaluation, primarily to address logistical issues, is needed to assess its potential use with selected USAF units.

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Introduction

The United States Air Force (USAF) has been assessing the aerobic fitness level of its employees for about 30 years. During this time there has been a continual effort to develop and refine the best and most appropriate aerobic assessment. The latest efforts have been studies by Pollock et al. (22), DeWolfe et al. (6), and Flatten et al. (9). These efforts have led to changes and improvements in the assessment process, but they have also shown the need for continued efforts to improve the aerobic assessment procedure.

Three approaches can be taken in seeking to improve the aerobic assessment procedure of the USAF. (1) Continue to modify and refine the current assessment. (2) Find an assessment that has already been developed, test it, and if it is better than the current assessment, modify it for use by the USAF. (3) Use the knowledge and information gained from over 40 years of exercise testing by the scientific community and attempt to develop a new assessment. Since approach #1 has been done previously, a decision was made to pursue approaches #2 and #3.

A thorough review of the literature uncovered a submaximal CE test to estimate VO_{2max} developed by Legge and Banister (18) that had results superior to any other submaximal or field exercise test. If this protocol could excel under cross-validation, it would result in a major improvement in the USAF aerobic assessment procedure. Therefore, it was deemed prudent and wise to evaluate this protocol.

In 1981, Whipp, Davis, Torres and Wasserman (27) assessed the efficacy of using a ramp CE protocol in determining VO_{2max}. They determined that a ramp test was a viable protocol to use in measuring VO_{2max} and it has been accepted as such by the exercise science community. Storer, Davis and Caiozzo (24) used this principal in developing a ramp **maximal** cycle ergometer protocol to estimate VO_{2max}, but to our knowledge no one has developed a submaximal CE ramp protocol to estimate VO_{2max}.

Since ramp protocols are effective in maximal exercise testing, they may also be effective as submaximal tests to estimate VO_{2max}. Even if a ramp protocol is not superior to a traditional steady-state protocol, a ramp protocol has an immediate advantage in being able to reduce heart rate variability of the ending HR_{submax} that should result in fewer invalid tests. One previous hindrance to the use of ramp CE protocols has been the difficulty in quickly and accurately

changing the power output of cycle ergometers. The development of electronic, programmable cycle ergometers has eliminated this hindrance and makes conducting a ramp test very feasible.

After initial pilot testing, a decision was made to pursue two new CE protocols. One was a ramp protocol that increased 5 watts (W) every 20 seconds until 85% of estimated HR_{max} was achieved. This ramp was similar to the 15 W•min^{-1} ramp used by Storer, Davis and Caiozzo (24) and was the smallest increase in power output possible with the CE available for use in this study. This protocol also ensured that no subject would exercise above 85% of their estimated HR_{max} and that each subject was theoretically at the same estimated relative intensity during the final power output.

Since previous protocols use a steady-state period and no ramp submaximal cycle ergometer protocol had ever been developed, a decision was made to pursue a hybrid protocol, a ramp to steady-state protocol. This second protocol consisted of a ramp, which increased 5 W every 20 seconds until 70% of the estimated HR_{max} was achieved. At this time, the power output was maintained for a total of six minutes. Seventy per cent of estimated HR_{max} was selected as the power output for the final ramp stage and for the steady-state stage because pilot testing revealed that the HR at the end of the steady-state stage would be at or below 85% of estimated HR_{max}.

Most of this study was developmental in nature. Therefore, it was best to conduct it in phases. As discoveries were made and conclusions drawn, decisions and adjustments were made in proceeding toward the overall mandate of discovering or developing a better exercise test to estimate VO_{2max}. First, a cross-validation of the Banister-Legge protocol (18) and an initial data collection for the development of ramp and ramp steady-state equations were conducted. This initial data collection determined that the Banister-Legge protocol (18) was not a viable option for the USAF and that more data was needed from the development of equations for the ramp and ramp steady-state protocols. Therefore, no more data were collected from the Banister-Legge protocol (18) and more ramp and ramp steady-state data were collected.

After the additional data for the ramp and ramp steady-state data were collected, the logical step was to conduct a modest cross-validation of the ramp and ramp steady-state equations before a major cross-validation of either of these protocols was started. A decision was also made to simultaneously pursue an evaluation of the Kline et al. (17) 1-mile walk test.

The 1-mile walk test was pursued because it has a correlation coefficient and SEE values similar to the current USAF CE test and it may have logistical advantages over a cycle ergometer test and the previously used 1.5 mile run.

Therefore, Phase 1A was the assessment of the Banister-Legge protocol. Phase 1B was the development of new CE protocols. Phase 2 was the comparison of the 1-mile walk test, the USAF CE and the new ramp and ramp steady-state protocols.

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Phase 1A

Assessment of the Banister-Legge Protocol

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Introduction

Legge and Banister (18) developed a submaximal CE and nomogram based upon the linear relationship between VO_2 and ΔHR (final submaximal HR - unloaded cycling HR) to estimate VO_{2max}. They developed this nomogram, known as the Banister-Legge (B-L) nomogram, using 15 trained and 10 untrained 20 to 29 year old males and then validated it with five trained, five untrained, and four moderately trained 20 to 29 year old males. The B-L nomogram utilizes ΔHR and the final submaximal power output during a standardized protocol to estimate VO_{2max}.

In developing their nomogram, Legge and Banister (18) discovered that the slope of the ΔHR/submaximum power output was different for trained and untrained subjects. At the same power output, untrained subjects had a greater ΔHR than trained subjects. This allowed for the development of a separate nomogram for trained and untrained subjects.

In the validation portion of their study, Legge and Banister (18) reported a much higher correlation ($r = 0.98$) between the estimated and measured VO_{2max} and a lower SEE ($0.17\ l\bullet min^{-1}$ or $2.4\ ml\bullet kg^{-1}\bullet min^{-1}$) when estimating the VO_{2max} than other studies (4, 5, 9, 10, 11, 12, 13, 14, 15, 16, 19, 21, 23, 25, 26) that show correlation coefficients ranging from 0.39 to 0.94 and SEEs ranging from 3.3 to $10.7\ ml\bullet kg^{-1}\bullet min^{-1}$. The correlation and SEE shown by Legge and Banister were also better than the correlation (0.85) and SEE ($6.7\ ml\bullet kg^{-1}\bullet min^{-1}$) shown by Pollock et al. (22) in the cross-validation of the current USAF CE test with men.

Based on these results, the B-L nomogram may be the most accurate submaximal cycle ergometry test available for estimating VO_{2max} and may be a viable candidate to replace the USAF CE. However, to our knowledge, no further cross-validation of the B-L nomogram has occurred. Therefore, the purpose of Phase 1A was to cross-validate the B-L nomogram.

Methods

Subjects

Thirty-one healthy volunteer male subjects 18 – 30 years of age participated in this study. The study was approved by the Institutional Review Board at the University of Texas at Austin. Subjects were primarily recruited from Kinesiology and health education classes and by flyers distributed across the University of Texas at Austin campus. All subjects provided written

informed consent (see Appendix A) and completed a health and fitness screening questionnaire (See Appendix C) prior to participating in this study.

Experimental Design

Subjects who participated in Phase 1A also participated in Phase 1B. Over a period of about three weeks, each subject in Phase 1A and B completed a maximal treadmill (TM) test to volitional fatigue and then two, three or four randomly assigned cycle ergometry tests. In almost all cases, tests were conducted at least 48 hours apart during the same time of day (within ± 2 hours). For the purposes of this analysis, all 31 subjects in Phase 1A completed a maximal TM test and a submaximal-to-maximal CE test. A subset of 19 subjects also completed the USAF CE test. Each subject completed the submaximal-to-maximal CE test using a SensorMedics Ergo-Metrics 800-S cycle ergometer. The estimated VO_{2max} was determined from the submaximal portion of the submaximal-to maximal CE test following the procedures set forth by Legge and Banister (18). The maximal portion elicited the measured VO_{2max}.

Procedures

Subjects were instructed to refrain from food, nicotine, and caffeine for at least three hours prior to testing, and to refrain from alcohol and strenuous physical activity for at least 12 hours prior to testing. During their initial visit, subjects listened to an explanation of the study, signed an informed consent, filled out a personal health and fitness questionnaire and had their height measured to the nearest 0.1 cm. Upon reporting to the laboratory each testing day, the subject was weighed to the nearest 0.1 kg using a balance scale, fitted with a Polar HR Monitor™, and filled out a daily questionnaire (see Appendix C) relating to food, nicotine, and caffeine intake within the previous three hours, physical activity and medications taken in the previous 12 hours, hours of sleep during the previous night, and a general rating of "how do you feel." Prior to each cycle ergometer test, HR_{rest} was measured for two minutes while the subject was seated on the cycle ergometer. HR was recorded during the final 10 seconds of both minutes. During the initial visit HR_{rest} was measured for two minutes while the subject was seated in a chair before beginning the TM test.

During the exercise tests the HR was measured continuously using the Polar HR Monitor™. HR_{max} was the highest HR observed during the test. VO_2 was measured continuously

using a SensorMedics 2900 metabolic measurement cart and reported as a rolling average of three 20-second measurements. VO_{2max} was defined as the highest one-minute value observed during the test. The maximal tests were considered maximal if the respiratory exchange ratio (RER) was 1.10 or higher. Any subject not meeting the 1.10 criteria completed a second maximal test.

Pretest calibration and post-test verification of calibration were conducted. The gas analyzers were calibrated using standard medical grade calibration gases. The volume probe was calibrated using a 3.0 liter syringe. The CE was calibrated weekly with a manual calibration at 1.5 kg, and verification of this calibration was then conducted at 0.5, 1.0, 2.0, 2.5, 3.0 and 3.5 kg.

<u>Maximal Treadmill (TM) Test:</u> Prior to the maximal TM test, subjects were allowed a short warm-up period to familiarize themselves with walking on the TM. The TM protocol consisted of an initial speed of either four or five mph. Every two minutes the speed was increased one mph until a RER of at least 0.95 was observed. At the end of this stage, the TM grade was increased 2% every minute until volitional fatigue. At the point of volitional fatigue, the TM speed was reduced to two mph to allow the subject a three minute cool-down period.

HR was measured continuously using the Polar HR Monitor™. HR_{max} was the highest HR observed during the test. VO_2 was measured continuously using a SensorMedics 2900 metabolic measurement cart and reported as a rolling average of three 20 second measurements. VO_{2max} was defined as the highest one-minute value observed during the test.

Following the TM test and before leaving the laboratory, each subject completed a familiarization trial on the CE. Subjects cycled for four minutes with no resistance (unloaded cycling) and for four minutes at 50 W. The seat height for each subject was determined before beginning the TM test. The seat height was adjusted by having the subject sit on the bike with the heel of their foot on the pedal and leg fully extended. The subject was then instructed to place their foot inside the toe clips of the pedal and cycle for three to four revolutions. Seat height was accepted when the subject's leg was bent approximately five degrees when extended at the bottom of crank. This seat height was recorded and used for each subsequent CE test.

<u>Submaximal-to-maximal CE Test</u>: HR_{rest} was measured for two minutes while the subject was seated on the cycle ergometer. The submaximal-to-maximal CE test consisted of a five-minute unloaded cycling period followed by an initial power output of 50 W for three minutes

and power output increases of 50 Watts (W) every three minutes thereafter (e.g. 50, 100, etc.). This progression was maintained until the end of the stage in which a HR was achieved at or near 85% of estimated HR_{max} (HR_{max} = 220 – age). When 85% of predicted HR_{max} was achieved, the power output was increased by 25 W every two minutes until volitional fatigue. (Since subjects frequently were not exactly at 85% of estimated HR_{max} at the end of a stage, decisions had to be made on whether to continue the submaximal portion of the test or to progress to the maximal portion. Based on HR increases during previous stages, if the subject's HR would without question have exceeded 85% of estimated HR_{max} by proceeding to the next stage, 85% HR_{max} was considered achieved. Subjects always proceeded to the next submax stage if it was not certain that their HR would have exceeded 85% of estimated HR_{max}. If the subject's HR exceeded 85% of estimated HR_{max} during a stage, data from the previous stage were used for analysis). Subjects then completed three minutes of unloaded cycling for a cool-down. Power output max was the highest power output maintained for at least one minute. Subjects were instructed to cycle at 90 rpm according to the original instructions for using the B-L nomogram. Subjects and test technicians monitored this by watching the LED output on the control.

HR was measured continuously using the Polar HR Monitor™ and recorded manually at the end of each minute. HR_{max} was the highest HR observed during the test. VO_2 was measured continuously using a SensorMedics 2900 metabolic measurement cart and reported as a rolling average of three 20 second measurements. VO_{2max} was defined as the highest one-minute value observed during the test.

The estimated VO_{2max} was determined using the procedures set forth by Legge and Banister (18). Variables needed for this determination were: (1) the HR during the last minute of unloaded cycling ($HR_{unloaded}$), (2) the steady-state HR and power output that elicited approximately 80% of the subjects age predicted VO_{2max}, and (3) the estimated submaximal VO_2 in one $\bullet$ min^{-1}. This power output was calculated with the equation 0.0117 x Watts + 0.39 from Table 2 in the Legge and Banister manuscript (18), and (4) the ΔHR (HR_{submax} - $HR_{unloaded}$). (Since no specific method was given in the manuscript by Legge and Banister (18) for determining the power output that elicited approximately 80% of the subjects age predicted VO_{2max} (step 2 above), the power output eliciting approximately 85% of estimated HR_{max} was used. The published manuscript and the dissertation that this manuscript is based on were examined

carefully in an attempt to identify the method used, but it was not given. Subjects were classified as trained or untrained by plotting ΔHR and the estimated submaximal VO_2. Tables for trained and untrained subjects generated by the B-L nomogram and provided in the Legge and Banister study (18) were then used to estimate VO_2 from the ΔHR and submaximal power output.

Air Force Submaximal Cycle Ergometry Assessment (USAF CE). The USAF CE assessment is a branching power output protocol based upon the HR responses of the subject being tested. The USAF assessment is designed to estimate VO_{2max} using the HR response between 125 beats per minute (bpm) and 85% predicted HR_{max}. The current USAF CE consists of a two-minute warm-up period at a power output of 25 W (≅0.5 kilograms) for females or 50 W (≅1.0 kilograms) for males, a three-minute power output progression phase in which the HR response is evaluated every minute to determine necessary power output progressions, and a six minute steady-state period. A steady-state HR of ± 3 bpm must be achieved. Subjects completed this assessment while pedaling at 50 rpm.

A submaximal cycle ergometry study of the USAF assessment conducted by Flatten et al. (8) indicated three two-minute power output progression stages were superior to three one-minute power output progression stages in producing valid test results. Also, the original Åstrand- Ryhming protocol (1,2) used a ± 5 bpm difference as a steady state HR response in the last two minutes of the test. Therefore, the protocol used for this study contained three two-minute power output progression stages and allowed for a ± 5 bpm difference in the last two minutes of the steady state period to be considered a valid test. HR_{rest} was measured for two minutes while the subject was seated on the cycle ergometer. A three-minute cool-down period cycling at 20 W was also added to the assessment. VO_{2max} was estimated using the USAF Fitness Program Calculator Rev 3.1, July 1998.

Statistical Analysis

A paired t-test was used to determine if there was a significant difference ($p < 0.05$) between the VO_{2max} measured on the CE and the VO_{2max} estimated by the B-L nomogram. The accuracy of the B-L nomogram was evaluated using correlation coefficient (r), mean difference, SEE and total error (E). {$E = \sqrt{\Sigma(Y-Y')^2/N}$ where Y equals the measured value and Y' equals the predicted value.} The number of estimated VO_{2max} values within 5% and outside of 15% of the actual VO_{2max} was also determined.

In the subset of 19 subjects who completed the USAF CE and the B-L protocol, the VO_{2max} estimated by the B-L nomogram and the USAF CE could not be compared directly because the B-L nomogram estimates to a CE VO_{2max}, while the USAF CE estimates to a TM VO_{2max}. Therefore, the same statistical procedures described above were used to compare the VO_{2max} estimated by the B-L nomogram with the VO_{2max} measured on the CE and to compare the VO_{2max} estimated by the USAF CE with the VO_{2max} measured on the TM.

Results

Banister-Legge Cross-Validation

Of the 31 subjects completing this study, five did not achieve steady-state HRs at the final submaximal power output and only one of the remaining 26 subjects was classified as "trained." A decision was made to validate the B-L nomogram for only "untrained" subjects and analyses were conducted on 25 subjects. Table 1 gives the characteristics of these 25 subjects (and of the 19 subjects used in the comparison of B-L and USAF CE). They had VO_{2max} values similar to the untrained (46.8 ml• kg^{-1}• min^{-1}), but lower than the trained (70.3 ml• kg^{-1}• min^{-1}) subjects of Legge and Banister (18). The average ending HR_{submax} was 86% of the actual HR_{max} and 83% of the predicted HR_{max}.

TABLE 1. PHYSICAL & PHYSIOLOGICAL CHARACTERISTICS OF SUBJECTS FOR B-L CROSS-VALIDATION

Variables	Values (N = 25)	Values (N = 19)
Age (yr)	24.2±3.4	23.2±3.0
Weight (kg)	77.1±12.3	78.5±13.1
Height (cm)	177.0±8.1	177.1±8.4
Measured Bike VO_{2max} (l·min^{-1})	3.66±0.55	3.74±0.51
Measured Bike VO_{2max} (ml·kg^{-1}·min^{-1})	48.1±6.8	47.7±6.4
Measured TM VO_{2max} (ml·kg^{-1}·min^{-1})	54.7±6.4	54.8±6.1
$HR_{unloaded}$ (bpm)	91.6±7.5	92.8±7.4
HR_{submax} (bpm)	163.4±7.1	165.1±6.2
HR_{submax}/Estimated HR_{max} (%)	83.4±3.4	83.9±3.2
HR_{submax}/Actual HR_{max} (%)	86.2±4.0	86.7±3.8
Bike HR_{max} (bpm)	189.9±10.9	190.7±9.5
TM HRmax (bpm)	196.4±9.6	197.9±8.7
ΔHR (bpm)	71.7±9.6	72.3±8.9
Power output max (W)	254.0±43.7	255.3±40.5

Values are mean ± SD; W = watts

Table 2 gives the statistical comparison of the CE measured and estimated VO_{2max} values. A paired t-test determined that the B-L untrained (UT) nomogram significantly underestimated the CE measured VO_{2max} (t = 8.4, $p < 0.0001$) by a mean difference of 0.62 $l \bullet min^{-1}$ (17%). The r, SEE and E were 0.76, 0.36 $l \bullet min^{-1}$ (9.8%) and 0.72 $l \bullet min^{-1}$ (19.7%), respectively. Eight per cent of the tests had ≤5% error and 64% of the tests had >15% error.

Legge and Banister found the slope of the ΔHR/power output to be different for trained and untrained subjects. This results in trained subjects, with the same ΔHR and submaximal power output as untrained subjects, having a higher estimated VO_{2max}. In developing their nomogram, Legge and Banister developed regression equations for trained and untrained subjects in which $\%VO_{2max}$ can be estimated from ΔHR. At the ending submaximal power output, our subjects were at 72% of their measured VO_{2max}, while the equation of Legge and Banister for untrained subjects estimated that they would be at 79% of their measured VO_{2max}. This could partially explain why the B-L nomogram consistently and significantly underestimated the measured VO_{2max} in our subjects. If the B-L regression equation for trained subjects was used with all of our subjects, the equation of Legge and Banister would predict them to be at 72% of their measured VO_{2max} and should result in a more accurate estimation of VO_{2max}. To test this, the VO_{2max} was estimated using the B-L nomogram for trained (T) subjects. As can be seen in Table 2, the estimated VO_{2max} using the T nomogram was still significantly lower than the measured VO_{2max} (t = 2.3, $p = 0.02$); however, the mean difference (0.62 to 0.18 $l \bullet min^{-1}$), E (0.72 to 0.44 $l \bullet min^{-1}$), and percentage of tests with more than 15% error (64% to 28%) decreased. Also, the percentage of tests with ≤5% error increased from 8% to 16%. The r was still lower and the SEE higher than in the original study by Legge and Banister.

TABLE 2. COMPARISON OF ESTIMATED (B-L) AND MEASURED (CE) VO_{2MAX}

Nomogram Used*** (n = 25)	M VO_{2max} ($l \cdot min^{-1} \pm SD$)	E VO_{2max} ($l \cdot min^{-1} \pm SD$)	Mean Diff ($l \cdot min^{-1}$)	r	SEE ($l \cdot min^{-1}$)	E ($l \cdot min^{-1}$)	≤5% (%)	>15% (%)
UT	3.66±0.55	3.04 ± 0.50	0.62*	0.76	0.36	0.72	8	64
T	3.66±0.55	3.48 ± 0.55	0.18*	0.73	0.38	0.44	16	28

*significantly different ($p < 0.001$); **significantly different ($p = 0.02$);M VO_{2max} = measured VO_{2max}; E VO_{2max} = Estimated VO_{2max}.

***Note: There are separate nomograms for trained (T) and untrained (UT) subjects. Whether a subject is considered T or UT is determined by the slope of the ΔHR/submaximum power output. Twenty-five of the 26 subjects who completed the study were classified as UT, so the one T subject was dropped, and only the UT nomogram was used. As explained, another analysis was completed in which the 25 subjects were classified as T.

B-L vs. USAF CE

Table 3 gives the comparison of the VO_{2max} max estimated by the B-L and USAF protocols for 19 subjects. Paired t-tests determined that the B-L UT ($t = 9.3, p < 0.001$) and B-L T ($t = 3.1, p < 0.01$) nomograms significantly underestimated the measured VO_{2max} bike and the USAF CE significantly underestimated ($t = 3.5, p = 0.003$) the measured VO_{2max} TM. The B-L UT had the highest *r*, while the B-L T had the lowest mean difference, SEE, and E, the most tests with ≤5% error, and the least number of tests with >15% error.

TABLE 3. COMPARISON OF ESTIMATED AND MEASURED VO_{2MAX} FOR THE B-L & USAF PROTOCOLS

(n = 19)	M VO_{2max} $ml \cdot kg^{-1} \cdot min^{-1}$ ±SD	E VO_{2max} $ml \cdot kg^{-1} \cdot min^{-1}$ ±SD	Mean Diff $ml \cdot kg^{-1} \cdot min^{-1}$	r	SEE $ml \cdot kg^{-1} \cdot min^{-1}$	E $ml \cdot kg^{-1} \cdot min^{-1}$	≤5% (%)	15% (%)
USAF	54.8 ± 6.1	48.7 ± 9.9	6.1*	0.65	4.6	9.6	11	47
B-L UT	47.7 ±6.5	39.0 ± 6.6	8.7*	0.81	3.8	9.5	11	74
B-L T	47.7 ±6.5	44.4 ± 6.2	3.2*	0.80	3.8	5.5	16	26

*significantly different ($p < 0.01$); M VO_{2max} = measured VO_{2max} TM for USAF and measured VO_{2max} bike for B-L; E VO_{2max} = Estimated VO_{2max}.

Discussion

Legge and Banister (18) developed a nomogram on 20- to 29-year old males for estimating VO_{2max} from a submaximal cycle ergometer test using ΔHR and submaximal power output. In their validation study they reported an $r = 0.98$ and a SEE = 0.17 $l \bullet min^{-1}$. The current study had a lower r (0.76) and higher SEE (0.36 $l \bullet min^{-1}$) than Legge and Banister.

Previous studies (4, 5, 9, 10, 11, 12, 13, 14, 15, 16, 19, 21, 23, 25, 26), using submaximal CE to compare estimated and measured VO_{2max}, have shown widely varying correlation coefficients (0.39 to 0.94) and SEEs (3.3 to 10.7 $ml \bullet kg^{-1} \bullet min^{-1}$). The r values in most of these studies range from 0.64 to 0.87, similar to the $r = 0.76$ of the current study, but lower than the $r = 0.98$ of Legge and Banister (18). The SEE from Legge and Banister (2.4 $ml \bullet kg^{-1} \bullet min^{-1}$) was lower than any previous study while the SEE from the current study (4.7 $ml \bullet kg^{-1} \bullet min^{-1}$) was at the lower end of the SEEs reported by previous studies. The higher r and lower SEE of Legge and Banister from their original study compared to the current study and previous studies (4, 5, 7, 10, 11, 12, 13, 14, 15, 16, 19, 21, 23, 25, 26) indicate that the B-L protocol clearly was not as accurate as originally indicated. This was not surprising given that the results of the B-L nomogram from their original study were even better than those of Storer et al. (24) who developed a regression equation to estimate VO_{2max} from a **maximal** CE test. In a study with 115 subjects, Storer et al. (24) determined that the correlation coefficient between estimated and measured VO_{2max} was 0.94 and the SEE was 0.21 $l \bullet min^{-1}$. It is highly unlikely that any submaximal test to estimate VO_{2max} will be more accurate than a maximal test to estimate VO_{2max}.

When data from the 19 subjects who completed the B-L and USAF CE tests were analyzed, both the B-L and USAF CE significantly underestimated the measured VO_{2max}. When the B-L nomogram for trained subjects was used, the B-L nomogram improved; however, this was an arbitrary decision to use the T nomogram with these subjects. One of the potential advantages of the B-L nomogram was its ability to distinguish between trained and untrained subjects. Since all but one subject in the current study was classified as "untrained" it was impossible to determine whether the B-L nomogram did indeed distinguish between trained and untrained subjects. It is interesting to note that the only subject classified as "trained" had a VO_{2max} of 43.8 $ml \bullet kg^{-1} \bullet min^{-1}$, which was lower than the mean VO_{2max} for the study. Even if the B-L nomogram can accurately distinguish between trained and untrained subjects, a different

nomogram would be needed for trained subjects since the T nomogram worked best for untrained subjects.

The current USAF CE data had a higher mean difference (11.1% vs. 3.4%) and E (17.5% vs. 16.9%), and a lower *r* (0.65 vs. 0.83) and SEE (8.4% vs. 14.7%) than the cross-validation of the USAF CE conducted by Pollock et al. (22) using a subset of subjects less than 35 years old.

Special Comments

Legge and Banister (18) did not include female subjects, but our original experimental design did. During pilot testing, it was determined that most women could not complete the B-L submax test because the 50 W increments were too large and steady-state HRs could not be attained. Therefore, twenty-four women completed a modified B-L protocol in which the power output increases were 25 W instead of 50 W. Since a new nomogram would need to be developed for this modified protocol and since our conclusion based on the male data was that the B-L nomogram was not superior to the current USAF CE, these data were not analyzed. Also, the pedaling rate of 90 rpm required by the B-L protocol was uncomfortable and difficult to maintain for many subjects, particularly the women.

Conclusions

The B-L nomogram did not perform nearly as well during this cross-validation as it did in the original research. While the B-L nomogram had a higher *r* than the USAF CE and therefore showed promise to be superior to the USAF CE, our recommendation is that the USAF should not pursue further development of the B-L nomogram. The reasons for this conclusion are: (1) the high number of invalid tests that result from the B-L nomogram; (2) the difficulty presented by pedaling at 90 rpm; (3) the unanswered questions regarding the untrained vs. trained nomogram and why the T nomogram worked the best with untrained subjects; and (4) further development would necessitate modification of the test for men and development of an entirely new test for women.

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Phase 1B

Development of New Protocols and Equations

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Introduction

The purpose of Phase 1B was to develop new protocols which would be more accurate in estimating VO_{2max} and produce fewer invalid tests than the current USAF CE. In 1981, Whipp, Davis, Torres and Wasserman (27) assessed the efficacy of using a ramp CE protocol in determining VO_{2max}. They determined that a ramp test was a viable protocol to use in measuring VO_{2max} and it has been accepted as such by the exercise science community. Storer, Davis and Caiozzo (24) used this information in developing a **maximal** CE protocol to estimate VO_{2max}, but to our knowledge a ramp protocol for a submaximal CE test has not been developed. It was hypothesized that a submaximal ramp protocol and a hybrid protocol which combined ramp and steady-state stages would produce estimated VO_{2max} as accurate or more accurate than the current USAF CE. Therefore, the purpose of this study was to develop two new submaximal protocols: (1) Ramp (R); and (2) Ramp to Steady-State (RSS) with equations to estimate VO_{2max}.

METHODS

Subjects

Fifty-nine M and sixty-five F, healthy subjects, 18-48 years of age volunteered for this study. One M and four F either did not complete the study or had invalid test results, so all results are based on 58 M and 61 F. (The one male was unable to achieve 85% of estimated HR_{max} during the R test. One of the female subjects had considerable HR variability during the tests and between tests. Because these tests were being conducted to develop new equations, her tests were not accepted as valid. Had she been tested for cross-validation or during a USAF testing these tests would have been valid. One of the other females was on a medication that could affect HR and the other two did not complete the study.) The number of subjects in each age category who completed Phase 1B were: 18 - 29 yrs of age--29 M and 31 F; 30 - 39 yrs of age--16 M and 16 F, and 40 - 48 yrs of age--13 M and 14 F. (The subjects in Phase 1A were also a part of Phase 1B.) Study approval, subject recruitment, informed consent and medical screenings were the same as in Phase 1A. Table 4 gives the physical and physiological characteristics of the Phase 1B subjects.

TABLE 4. SUBJECT CHARACTERISTICS FOR DEVELOPMENT OF NEW EQUATIONS

Variable	Male (n = 58)	Female (n = 61)
Age (yrs)	31.1 ± 9.2	30.0 ± 9.6
Weight (kg)	78.8 ± 13.3	60.3 ± 9.6
Height (cm)	177.4 ± 7.0	163.2 ± 5.3
BMI (kg/m^2)	25.0 ± 3.8	22.6 ± 3.1
VO_{2max} ($ml \cdot kg^{-1} \cdot min^{-1}$)	50.2 ± 8.4	41.2 ± 7.9
HR_{max} (bpm)	193.1 ± 11.7	190.0 ± 10.0

Values are mean±SD

Experimental Design

For this phase, a maximal treadmill test (TM) and a ramp (R) and ramp to steady-state (RSS) submaximal CE tests were conducted. After data were collected, step-wise multiple regression techniques were used to develop equations to estimate VO_{2max} TM from both the R and RSS CE tests.

Procedures

The only differences in procedures for Phase 1A and 1B were the additions of the R and RSS protocols and women in Phase 1B.

Maximal TM Test: Refer to the Procedures section of Phase 1A for a description of the TM testing. The only differences were that, for women, the initial TM speed was either 3 or 4 mph instead of 4 or 5 mph and during the familiarization on the CE women pedaled at a power output of 30 W instead of 50 W.

Ramp Protocol (R): The R protocol began with a three-minute unloaded cycling period. At the end of the unloaded cycling period, the power output was set at 25 W or 50 W for F and M, respectively, for the first 20 seconds. The power output was then increased 5 W every 20

seconds until the end of the 20-second period in which 85% predicted HR_{max} was observed. The power output was then reduced to 20 W for a three-minute recovery period. HR was recorded at the end each 20-second period during the ramp progression and the end of each minute during unloaded cycling and recovery. VO_2 was reported every 20 seconds during the ramp progression as the rolling average of the three previous 20-second measures. During the unloaded cycling and recovery periods, the VO_2 values were reported as the one-minute average of three 20-second measurements. All pedaling was done at 75 rpm.

Ramp Steady-State Protocol (RSS): The RSS protocol began with a three-minute unloaded cycling period. After the unloaded cycling period, the power output was set at 25 and 50 W for F and M, respectively, for the first 20 seconds. The power output then increased 5 W every 20 seconds until the end of the 20-second period in which 70% predicted HR_{max} was observed. This power output was then maintained for a total of six minutes. At the conclusion of the six-minute steady-state period, subjects completed a three-minute recovery period at 20 W. HR was recorded at the end of each 20-second period during the ramp progression and during the last 10 seconds of each minute during the unloaded cycling period, the six-minute steady-state period, and the recovery period. VO_2 was reported every 20 seconds as the rolling average of the three previous 20-second measures during the ramp progression and reported as the one-minute average during unloaded cycling, the six-minute steady-state period, and the recovery period.

Statistical Analysis

Step-wise multiple regression techniques were used to develop equations to estimate VO_{2max} from the R and RSS protocols. For the R protocol two independent attempts to develop equations were employed. The UT-Austin group and consultants from CDSI (Computer Data Systems International, Ms. Susan Chao, Biostatistician/CDSI contractor for the Office of Prevention and Health Service Assessment) developed equations. Both UT and CDSI developed equations with and without ventilation (V_E) as a potential independent variable. The measurement of V_E by the USAF during CE is not currently feasible, but if the addition of V_E improves the accuracy of the CE significantly, then future equipment purchases and the use of V_E may be warranted. In developing the R equations, VO_{2max} TM was the dependent variable. Separate equations for M and F were developed. Potential independent variables included age, height, weight, BMI (kg/m^2), PO_{sub} (ending submaximal power output in watts), PO_{sub}/kg (ending

submaximal power output in watts divided by body weight), HR_{rest} (average of the two-minute HR recorded prior to starting the test), $HR_{unloaded}$ (average of the last two minutes of HR during unloaded cycling), HR_{sub} (the final submax HR), $HR_{recovery}$ (the HR after one-minute of recovery), $HR_{sub-rest}$ (the final submax HR - HR_{rest}), $HR_{sub-unloaded}$ (the final submax HR minus the $HR_{unloaded}$), $HR_{sub-recovery}$ (the HR_{sub} minus $HR_{recovery}$) and V_{Esub} (V_E for the last minute of the submax ramp).

Only the UT-Austin group developed equations for the RSS protocol. All procedures were the same as with the R protocol. Potential independent variables were the same with several additions. These additional potential independent variables primarily involved using two submaximal points: (1) sub1 - the first 20-second interval of the six-minute steady-state and (2) sub2 - the average of the HR taken at minutes five and six and the V_E for minute six of the steady-state. The additional potential independent variables were HR_{sub1} (HR at the end of the last 20-second R period), HR_{sub2} (average of the two HRs taken at minutes five and six of the steady-state), $HR_{sub1-rest}$ (HR for the last 20 seconds of the ramp minus the two-minute resting HR), $HR_{sub2-rest}$ (average of the two HRs taken at minutes five and six of steady-state minus the two minute resting HR), $HR_{sub1-unloaded}$ (HR for the last 20 seconds of the ramp minus the average of the two HRs taken at minutes two and three during unloaded cycling), $HR_{sub2-unloaded}$ (HR for the last two minutes of SS minus the HR for the average of the two HRs taken at minutes two and three during unloaded cycling), $HR_{sub2-sub1}$ (average of the two HRs taken at minutes five and six of the steady-state minus the HR during the last 20 seconds of the ramp), V_{Esub1} (V_E at the end of the last 20-second R period), V_{Esub2} (V_E for the last minute of the steady-state period), $V_{Esub2-sub1}$ (V_E for the last minute of the steady-state period minus the V_E during the last 20 seconds of the ramp), V_{Esub1}/kg (V_E at the end of the last 20-second R period divided by body weight in kg), and V_{Esub2}/kg (V_E for the last minute of the steady-state period divided by body weight in kg). Also, in the R protocol subjects were by the nature of the test very close to 85% of predicted HR_{max} at the end of the R progression. In the RSS protocol, subjects were very close to 70% of predicted HR_{max} at the end of the ramp progression, but at the end of the steady-state period there was a greater variation in HR. Therefore, another potential independent variable was $\%HR_{maxsub2}$ (HR_{sub2}/(220-age)).

Results

Development of New Equations

The equations developed by UT and by CDSI for the R protocol are given in Tables 5 and 6, respectively. A comparison of the UT and CDSI equations reveals: (1) that in the equations without V_E for men the same variables (PO_{sub}/kg, age and body weight) were in both the UT and CDSI equations, but HR_{sub} also achieved significance for CDSI; (2) that in the equations without V_E for women both the UT and CDSI equations included PO_{sub}/kg, but the UT equation included age and BMI while the CDSI equation included $HR_{unloaded}$; (3) that in the equations with V_E for men both the UT and CDSI equations included PO_{sub}/kg, age and V_E, but the CDSI equation also included HR_{sub}; and (4) that for both the UT and CDSI when V_E was added as a potential independent variable for women, it did not achieve significance. Therefore, there were no equations for women that included V_E.

TABLE 5. EQUATIONS DEVELOPED BY UT FOR ESTIMATING TM VO_{2MAX} FROM THE R PROTOCOL

RUT1M (M without V_E)	VO_{2max} = (8.766 x PO_{sub}/kg) - (0.226 x Age) - (0.124 x Wgt) + 43.78
RUT1F (F without V_E)	VO_{2max} = (7.13 x PO_{sub}/kg) - (0.20 x Age) - (0.53 x BMI) + 43.1
RUT2MV (M with V_E)	VO_{2max} = (12.889 x PO_{sub}/kg) - (0.22 x Age) - (0.196 x V_{Esub}) + 36.07
RUT2FV (F with V_E)	V_{Esub} did not achieve significance and therefore there is no equation

VO_{2max} = ml• kg^{-1}• min^{-1}; PO_{sub}/kg = ending submax power output in Watts/ Weight in kg; Age = age in yrs; Wgt = weight in kg; BMI = Weight in kg/height in Meters^2; V_E = ventilation STPD.

TABLE 6. EQUATIONS DEVELOPED BY CDSI FOR ESTIMATING TM VO_{2MAX} FROM THE R PROTOCOL

RCDSI3M (M without V_E)	$VO_{2max} = (9.07 \times PO_{sub}/kg) - (1.13 \times Age) - (0.12 \times Wgt) - (1.05 \times HR_{sub}) + 239.0$
RCDSI3F (F without V_E)	$VO_{2max} = (11.81 \times PO_{sub}/kg) + (0.16 \times HR_{unloaded}) + 0.32$
RCDSI4MV (M with V_E)	$VO_{2max} = (13.13 \times PO_{sub}/kg) - (1.02 \times Age) - (0.19 \times V_E) - (0.93 \times HR_{sub}) + 209.6$
RCDSI4FV (F with V_E)	V_{Esub} did not achieve significance and therefore there is no equation

$VO_{2max} = ml \cdot kg^{-1} \cdot min^{-1}$; PO_{sub}/kg = ending submax power output in Watts/ Weight in kg; Age = age in yrs; Wgt = weight in kg; V_E = ventilation STPD; $HR_{unloaded}$ = average HR for last two min of unloaded cycling; HR_{sub} = HR at the final power output.

The equations developed by UT for the RSS protocol are given in Table 7. A comparison of the UT R and RSS equations reveals: (1) that in the equations without V_E for men, both the R and RSS equations included PO_{sub}/kg and weight, but the R equation included age and the RSS equation included HR variables; (2) that in the equations with V_E for men, both the R and RSS equations included PO_{sub}/kg and age, the V_E achieving significance in the RSS equation was the V_E at the end of the steady-state period, and the RSS equations included two different HR measures ($HR_{unloaded}$ and $\%HR_{maxsub2}$); (3) that in equations without V_E for women, both the R and RSS equations included PO_{sub}/kg and a weight related variable (the R equation included BMI while the RSS equation included weight), and the R equation included age while the RSS equation included HR variables; and (4) that for both R and RSS, V_E does not achieve significance and was not included in an equation.

TABLE 7. EQUATIONS DEVELOPED BY UT FOR ESTIMATING TM VO_{2MAX} FROM THE RSS PROTOCOL

RSS1M (M without V_E)	$VO_{2max} = (0.426 \times HR_{unloaded}) + (13.654 \times PO_{sub}/kg) + (0.19 \times HR_{sub2\text{-}rest}) - (101.41 * \%HR_{maxsub2}) - (0.170 * Wgt) + 67.25$
RSS2MV (M with V_E)	$VO_{2max} = (0.196 \times HR_{unloaded}) + (17.469 \times PO_{sub}/kg) - (0.252 * V_{Esub2}) - (0.181 * Age) - (41.069 * \%HR_{maxsub2}) + 52.20$
RSS1F (F without V_E)	$VO_{2max} = (0.271 \times HR_{sub1}) + (9.138 \times PO_{sub}/kg) - (78.171 * \%HR_{maxsub2}) - (0.164 * Wgt) + 62.77$
RSS2F (F with V_E)	V_{Esub} did not achieve significance and therefore there is no equation

VO_{2max} = ml• kg^{-1}• min^{-1}; PO_{sub}/kg = ending submax power output in Watts/ Weight in kg; $HR_{sub2\text{-}rest}$ = average HR of the last two min of RSS minus the resting HR; $\%Max_{sub2}$ = average HR of the last two min of RSS divided by the predicted HR_{max}; $V_{Esub2} = V_E$ during the last minute of steady-state; Age = age in yrs; HR_{sub1} = HR during the last 20 seconds of the ramp; Wgt = weight in kg; $HR_{unloaded}$ = average HR for last two min of unloaded cycling; HR_{sub} = HR at the final power output.

Evaluation of New Equations

As a preliminary evaluation of the new equations, data from the R and RSS tests were entered into the R and RSS equations. The estimated VO_{2max} values are given in Tables 8 and 9. Paired t-tests were used to compare the estimated VO_{2max} from each equation with the measured VO_{2max}. There were no significant differences between measured and estimated VO_{2max} except for RCDSI2M. When the R and RSS equations were compared and the equations with and without V_E were compared, there was a tendency for the RSS equations and the equations without V_E to have a higher *r*, lower SEE and E, more tests with ≤5% error and fewer tests with >15% error.

TABLE 8. COMPARISON OF ESTIMATED AND MEASURED VO_{2MAX} FOR WOMEN FROM R AND RSS PROTOCOLS

n = 61	E VO_{2max} ml• kg^{-1}• min^{-1}±SD	Mean Diff ml• kg^{-1}• min^{-1}	r	SEE ml• kg^{-1}• min^{-1}	E ml• kg^{-1}• min^{-1}	≤5% (%)	>15% (%)
RUT1F	41.1 ± 6.7	0.07	0.85	4.2	4.2	33	13
RCDSI3F	41.7 ± 6.9	0.49	0.82	4.5	4.5	34	16
RSS1F	41.2 ± 7.3	-0.00	0.92	3.1	3.0	44	3

Measured VO_{2max} TM equals 41.2±7.9; E VO_{2max} = estimated VO_{2max}.

TABLE 9. COMPARISON OF ESTIMATED AND MEASURED VO_{2MAX} FOR MEN FROM THE R AND RSS PROTOCOLS

n = 58	E VO_{2max} $ml \cdot kg^{-1} \cdot min^{-1}$ ±SD	Mean Diff $ml \cdot kg^{-1} \cdot min^{-1}$	r	SEE $ml \cdot kg^{-1} \cdot min^{-1}$	E $ml \cdot kg^{-1} \cdot min^{-1}$	≤5% (%)	>15% (%)
RUT1M	50.4 ± 7.2	0.20	0.86	4.3	4.3	43	14
RUT3MV	49.9 ± 7.5	0.30	0.89	3.8	3.7	48	2
RCDSI2M	48.5 ± 7.3	1.71*	0.85	4.4	4.6	43	12
RCDSI4MV	49.3 ± 7.5	0.84	0.90	3.7	3.8	47	2
RSS1M	50.1 ± 7.6	0.07	0.91	3.5	3.5	55	2
RSS2MV	50.2 ± 7.6	-0.03	0.91	3.5	3.7	50	5

*significantly different $p < 0.05$; Measured VO_{2max} TM equals 50.2±8.4; E VO_{2max} = estimated VO_{2max}

Discussion

In developing the equations to estimate VO_{2max}, a large number and variety of potential independent variables were used in an attempt to improve the accuracy over previous equations. One unique variable that was used as a potential independent variable was PO_{sub}/kg. PO_{sub} is a significant independent variable in other submax CE equations for estimating VO_{2max}, but, to our knowledge, no one has ever evaluated PO_{sub}/kg as a potential independent variable. In all of the equations developed, PO_{sub}/kg was a significant independent variable. Since PO_{sub}/kg and PO_{sub} are very similar and since PO_{sub}/kg was a significant independent variable, it was not surprising that PO_{sub} was not a significant independent variable. Had PO_{sub}/kg not been used as a potential independent variable, then PO_{sub} would have been a significant independent variable and would have been included in the equations.

V_{Esub} was evaluated as a potential independent variable. Surprisingly, V_{Esub} achieved significance for men but not for women. Analyzing this difference between men and women was not pursued since it was outside the purpose of this study. While V_{Esub} was a significant independent variable, the equations that included VE do not appear to be superior enough to those without V_E to justify further analysis of the V_E protocols.

The statistical analysis of the equations developed was slightly better than those of Pollock et al. (22) in their cross-validation of the current USAF CE test. This indicates that the new protocols and equations have promise; however, the question is how they will perform during cross-validation.

While a cross-validation study is needed to determine the accuracy of the new equations, reducing the frequency of invalid tests was another objective of the study. For the R protocol there was one invalid test for men (1.6%) and no invalid tests for women. For the RSS protocol no male subjects exceeded 85% of HR_{max} by more than 1 bpm at the end of RSS and only two women exceeded 85% of HR_{max} by more than 1 bpm. In these two cases, the HR exceeded 85% by 6 and 10 bpm, respectively. If 90% of estimated HR_{max}, the upper end of the recommended intensity used by ACSM in exercise prescription, was used as the cutoff for an invalid test, then only one of these two females would have had an invalid test.

HRs in excess of 85% of estimated HR_{max} would not alter the accuracy of the RSS protocol, so safety considerations are the criteria to be used in determining an upper HR limit for valid tests. If 85% of estimated HR_{max} is used as the criteria for an invalid test, the actual number of invalid tests that occurred in this study are similar to the number of invalid tests that theoretically were predicted. The only invalid tests from the R test should be those in which the subject is unable to achieve 85% of estimated HR_{max}. If a standard deviation in the estimation of HR_{max} is taken to be ±12 b/min, then HRs of 85% of estimated HR_{max} and two standard deviations below predicted HR_{max} are very similar. For example, a 30 yr old has an estimated HR_{max} of 190 bpm. A HR of 161.5 bpm is 85% of this estimated HR_{max} and a HR of 164 bpm is two standard deviations below the estimated HR_{max} (190 - 24). For a 50 yr old, a HR of 146 bpm is two standard deviations below the estimated HR_{max} and 145 bpm is 85% of the estimated HR_{max}. Therefore, slightly less than 2.5% of the tests would be invalid.

The only invalid tests from the RSS test should be from cases when the HR exceeds 85% of estimated HR_{max} during the RSS period. For a 20, 30, 40 and 50 yr old the difference between 70% and 85% of estimated HR_{max} is 30, 28, 27, and 25 bpm, respectively. In the current study, HR increased during the RSS period by 13.1± 6.3 bpm for men and by 15.4±7.1 bpm for women. An increase in HR of the mean plus two standard deviations during the RSS period (26 - 30 bpm) is about the same as the difference between 70% and 85% of HR_{max}. Therefore, one can

anticipate about 2.5% of the tests will be invalid. Note: a steady-state HR was not required for analysis in this study. The average HR of the last two minutes of steady-state was determined regardless of the differences between the two HRs.

Special Comments

Other avenues for developing equations were also investigated. One avenue was an attempt to find or develop a better estimation of HR_{max}. A thorough literature review was conducted to find different equations to estimate HR_{max}. These equations were evaluated against pilot and preliminary data and no method superior to 220 - age was found. An attempt was made to develop a better equation for estimating HR_{max} using physical and physiological data from approximately 700 maximal bike tests from the HERITAGE Family Study (3), but again a better equation was not identifiable. Another avenue was an attempt to identify subjects whose VO_{2max} values were most inaccurately estimated by the equations. The rationale was that perhaps there was something unique about these subjects that would make them identifiable. If these subjects could be identified, perhaps a special correction factor for them could be developed. A variety of methods were used in an attempt to identify characteristics unique to these subjects, but all methods failed.

Phase 2

Comparison of the one-mile walk, USAF CE and the New R and RSS Equations

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Introduction

In 1987, Kline et al. (17) developed a one-mile walking test to predict VO_{2max}. Subjects, 30 to 69 years of age, were randomly assigned to a development (n = 174) or a cross-validation group (n = 169). Each subject completed a modified Balke treadmill test in which VO_{2max} was measured directly and at least two 1-Mile Walk Tests. Multiple regression equations to estimate VO_{2max} yielded correlation coefficients of $r = 0.85 - 0.93$ with SEEs of 0.249 - 0.358 $l \bullet min^{-1}$ and 4.5 - 5.3 $ml \bullet kg^{-1} \bullet min^{-1}$. Cross validation yielded correlation coefficients of $r = 0.81 - 0.92$ and SEEs of 0.249 - 0.335 $l \bullet min^{-1}$ and 4.0 - 4.4 $ml \bullet kg^{-1} \bullet min^{-1}$. Since Kline et al. (17) developed this equation using 30 to 69 year old subjects, Dolgener, Hensley, Marsh, and Fjelstul (7) validated it using 196 college-aged (19.4±2.7 years of age) subjects. They found the Kline et al. (17) equation to have a lower r ($r = 0.39 - 0.59$) and higher SEE (SEE = 4.4 - 7.4 $ml \bullet kg^{-1} \bullet min^{-1}$) with this younger age group.

Since data from Kline et al. (17) indicate that the one-mile walk may be at least as accurate as the USAF CE and because there are some logistical advantages to the 1-Mile Walk Test, the test may be a viable option for use by selected USAF units (i.e...those without access to CE test facilities). Therefore, the purpose of this phase of the study was: (1) to compare two VO_{2max} prediction tests: the Kline et al. (17) 1-Mile Walk Test and the USAF CE; and (2) to compare four VO_{2max} prediction tests: the Kline et al.(17) 1-Mile Walk Test, the USAF CE, and the R and RSS tests developed in the first phase of this project.

Methods

Subjects

The subject population for comparing the 1-Mile Walk Test and USAF CE test consisted of 36 F and 31 M, while a subset of this population (20 F and 17 M) was used to compare all four tests. Subject characteristics are given in Table 10.

Procedures

Procedures for this phase of the study were the same as in Phase 1. The equations developed in Phase 1 were used for estimating the VO_{2max} for males and females from the R and RSS tests. The 1-Mile Walk Test was the only additional test conducted. For the one-mile walk, subjects walked on a measured indoor track (7.5 laps/mile) where the temperature was

maintained between 70° and 72° F. Since the track was not a competition track and not accurately measured, the distance was accurately determined using a certified measuring wheel. Subjects were instructed to walk one mile as fast as possible without running. HR was recorded every five seconds using a Polar Heart Watch. The average HR over the last two minutes was determined, recorded and used in the equation for estimating VO_{2max}. A technician timed, counted laps, and monitored each test.

Kline et al. (17) developed equations that estimated VO_{2max} in $l \cdot min^{-1}$ and in $ml \cdot kg^{-1} \cdot min^{-1}$. Since the USAF CE and the new equations for the R and RSS equations estimate VO_{2max} in $ml \cdot kg^{-1} \cdot min^{-1}$, the Kline et al (17) equations that estimated VO_{2max} in $ml \cdot kg^{-1} \cdot min^{-1}$ were used. The equations used from Kline et al. (17) are given in Table 11. These equations included a generalized equation that included both men and women (General) and separate equations for men (Men) and women (Women).

TABLE 10. SUBJECT CHARACTERISTICS FOR PHASE 2

	All Subjects			Subset for Comparing All Four Protocols		
	All (n = 67)	Male (n = 31)	Female (n = 36)	All (n = 37)	Male (n = 17)	Female (n = 20)
Age, yr	26.9± 6.5	27.0±5.0	26.9±7.6	28.1± 6.4	27.6±4.1	28.5±8.0
Height, cm	170.1±9.7	177.1±8.3	164.0±5.9	171.2±10.4	179.3±8.0	164.3±6.8
Weight, kg	73.5±17.8	80.2±15.1	67.8±18.1	78.7±20.1	85.1±15.7	72.7±21.6
BMI, kg/m^2	25.3±5.0	25.5±4.1	25.1±5.7	26.6±5.7	26.6±4.9	26.7±6.4
VO_{2max} TM $ml \cdot kg^{-1} \cdot min^{-1}$	45.7±11.6	51.7±11.6	40.6±9.0	43.0±12.1	49.6±12.3	37.3±8.7
HR_{max}, bpm	191.0±11.7	193.0±11.5	189.3±11.7	191.1±13.0	194.2±12.3	188.4±13.3

Values are mean±SD

TABLE 11. EQUATIONS FOR ESTIMATING VO_{2MAX} ($ML \cdot KG^{-1} \cdot MIN^{-1}$) FROM THE KLINE ET AL.(17) ONE-MILE WALK

General	VO_{2max} = 132.85 + (6.3150 x Sex) - (0.3877 x Age) - (0.0769 x Wgt) - (3.2649 x Time) - (0.1565 x HR)
Men	VO_{2max} = 154.899 - (0.0947 x Wgt) - (0.3709 x Age) - (3.9744 x Time) - (0.1847 x HR)
Women	VO_{2max} = 116.579 - (0.0585 x Wgt) - (0.3885 x Age) - (2.7961 x Time) - (0.1109 x HR)

Sex: 0 = female, 1 = male; Wgt = Weight in pounds; Time = time for the 1-mile walk expressed as minutes to hundredth of a minute; HR = HR in bpm at the end of last one-quarter mile (average HR over the last two minutes of the walk was used in the current study).

Table 12 gives a comparison of these three one-mile walk equations using the data from the subjects in the current study. Since there was no difference among the equations, only the General equation was used in comparing the one-mile walk, the USAF CE and the R and RSS equations.

TABLE 12. COMPARISON OF ESTIMATED AND MEASURED VO_{2MAX} FOR THE ONE-MILE WALK WITH GENERALIZED AND SEPARATE EQUATIONS FOR MEN AND WOMEN

	M VO_{2max} $ml \cdot kg^{-1} \cdot min^{-1}$	E VO_{2max} $ml \cdot kg^{-1} \cdot min^{-1}$	Mean Diff $ml \cdot kg^{-1} \cdot min^{-1}$	r	SEE $ml \cdot kg^{-1} \cdot min^{-1}$	E $ml \cdot kg^{-1} \cdot min^{-1}$	≤5% Error (%)	>15% Error (%)
Men's equation used with men (n = 31)	51.7±11.6	49.1±8.6	2.6	0.89	5.3	6.1	35	16
General equation used with men (n = 31)	51.7±11.6	49.5±7.2	2.2	0.89	5.2	6.4	39	19
Women's equation used with women (n = 36)	40.6 ± 9.0	41.1 ± 7.3	-0.5	0.87	5.6	4.4	36	14
General equation used with women (n = 36)	40.6 ± 9.0	41.2 ± 8.4	-0.6	0.89	4.1	4.1	42	14

M VO_{2max} equals measured VO_{2max} and E VO_{2max} equals estimated VO_{2max}.

Statistical Analysis

A repeated measures ANOVA was used to determine if there were any significant differences among the VO_{2max} values for the treadmill, one-mile walk and USAF CE. Correlation coefficients, mean difference, SEE, E and the percentage of tests estimating VO_{2max} within 5% and outside of 15% of the measured VO_{2max} were also calculated.

Paired t-tests were used to compare the measured VO_{2max} TM values with the VO_{2max} estimated by each of the R and RSS equations, the one-mile walk, and the USAF CE. Correlation coefficients, mean difference, SEE, E and the percentage of tests estimating VO_{2max} within 5% and outside of 15% of the measured VO_{2max} were also calculated.

Results

Comparison of one-mile walk and USAF

A repeated measures ANOVA determined that there were no significant differences among the VO_{2max} values from TM, one-mile walk, and USAF CE tests ($F = 2.77, p = 0.67$). Table 13 gives the statistical comparison of the one-mile walk and the USAF CE. While neither test elicited estimated VO_{2max} values that were significantly different ($p > 0.05$) than the measured VO_{2max}, the r, mean difference, SEE, E and the number of tests with ≤5% and >15% error were better for the one-mile walk than for the USAF CE. The r and SEE values for the one-mile walk and the USAF CE were similar to values from their respective cross validation studies (17, 21).

TABLE 13. COMPARISON OF VO_{2MAX} ESTIMATED BY THE ONE-MILE WALK & USAF CE

	Walk (n = 67)	USAF (n = 67)	Walk (Males; n=31)	USAF (Males; n=31)	Walk (Females; n=36)	USAF (Females; n=36)
M VO_{2max} ($ml \cdot kg^{-1} \cdot min^{-1}$)	45.7±11.6	45.7±11.6	51.7±11.6	51.7±11.6	40.6±9.0	40.6±9.0
E VO_{2max} ($ml \cdot kg^{-1} \cdot min^{-1}$)	45.0±8.8	43.5±14.5	49.5±7.2	47.3±16.7	41.2±8.4	40.2±11.5
Mean Diff	0.7±5.3	2.3±8.0	2.2±6.1	4.4±9.8	-0.6±4.1	0.4±5.6
r	0.901	0.833	0.893	0.821	0.888	0.877
SEE	5.03	6.42	5.23	6.62	4.11	4.30
E	5.3	8.3	6.4	10.6	4.1	5.6
≤5% Error (%)	40	27	39	23	42	31
>15% Error(%)	16	36	19	52	14	22

Values are mean ± SD; M VO_{2max} equals measured VO_{2max} and E VO_{2max} equals estimated VO_{2max}.

Because Dolgener et al. (7) found the Kline et al. (17) equation to have lower correlation coefficients with a younger, college-age population (19.4±2.7 years of age), data from the current study were also analyzed by two other methods. One was to limit the ages to those below the age of 25 years and the other was to limit the ages to those between 20 and 30 years of age. The results were very similar to those shown in Table 13. There were no significant differences between the measured and estimated VO_{2max} values for men or women under age of 25 years or between the ages of 20 and 30 years. The correlation coefficients in these analyses ranged from 0.80 - 0.89 and the SEEs ranged from 4.3 - 5.1 $ml \cdot kg^{-1} \cdot min^{-1}$.

Table 14 gives the comparison of the one-mile walk, the USAF CE, and the equations for the R and RSS for men. Paired t-tests were used to compare the estimated and measured VO_{2max} for each equation. There was no significant difference between the estimated and measured VO_{2max} for any equation. The USAF CE had a higher mean difference, SEE, and E, lower *r*, and more tests with greater than 15% error than any of the other equations. The RSS equations had lower mean difference, SEE and E, higher *r*, a higher percentage of tests with less than 5% error and a lower percentage with more than 15% error than the R equations. In a similar manner, the equations,

which included VE, tended to be better than the equations that did not include V_E. The accuracy of the best new equation which did not include V_E (RSS1M) was very similar to the one-mile walk equation, while the best new equation with V_E was slightly better than the one-mile walk equation.

TABLE 14. COMPARISON OF ESTIMATED AND MEASURED VO_{2MAX} FROM THE ONE-MILE WALK, USAF, R, & RSS EQUATIONS FOR MEN

n = 17	E VO_{2max} ml•kg^{-1}•min^{-1}	Mean Diff ml•kg^{-1}•min^{-1}	r	SEE ml•kg^{-1} •min^{-1}	E ml•kg^{-1} •min^{-1}	≤5% Error (%)	>15% Error (%)
Walk	47.8 ± 7.9	1.8	0.89	5.7	6.5	35	24
USAF	45.2±15.2	4.4	0.76	8.0	10.5	18	47
RUT1M	49.5 ± 9.0	0.1	0.83	6.8	6.7	18	29
RCDSI3M	48.1 ± 9.8	1.5	0.84	6.8	6.7	18	18
RUT2MV	48.6 ± 9.8	1.0	0.87	6.1	6.0	24	18
RCDSI4MV	48.6±10.6	1.0	0.87	6.1	6.0	35	12
RSS1M	49.6±10.6	-0.1	0.89	5.7	5.5	41	18
RSS2MV	50.1±10.2	-0.5	0.92	4.9	4.9	47	18

Measured VO_{2max} TM equals 50.2±8.4; E VO_{2max} equals estimated VO_{2max}.

Table 15 compares the different equations for women. There was a significant difference between the estimated and measured VO_{2max} for RCDSI3F and RSS1F. (Even though RSS1F was significantly different, it had the highest *r*, so it may just need refinement, (i.e...adjusting the intercept). The *r*, SEE, E and tests with ≤5% error were better for the RUT1F and the RSS1F than for the one-mile walk and the USAF CE. The results for the one-mile walk, the USAF CE, RUT1F, and RSS1F were very similar.

TABLE 15. COMPARISON OF ESTIMATED AND MEASURED VO_{2MAX} FROM THE ONE-MILE WALK, USAF, R, & RSS EQUATIONS FOR WOMEN

n = 20	E VO_{2max} ml• kg^{-1}• min^{-1}	Mean Difference ml• kg^{-1}• min^{-1}	r	SEE ml• kg^{-1}• min^{-1}	E ml• kg^{-1}• min^{-1}	≤5% Error (%)	>15% Error (%)
Mile	38.6 ± 8.8	-1.2	0.89	4.6	4.9	30	25
USAF	37.3±10.7	0.0	0.87	4.4	5.2	25	25
RUT1F	38.0 ± 7.5	-0.7	0.89	4.1	4.0	45	25
RCDSI3F	40.1 ± 7.0	-2.7*	0.82	4.9	5.0	35	30
RSS1F	39.3 ± 7.7	-1.9*	0.90	3.9	4.2	40	25

Measured VO_{2max} TM equals 37.3±8.7 ml• kg^{-1}• min^{-1}; E VO_{2max} equals estimated VO_{2max}.

Discussion

The new equations appear to be similar to or slightly better than the current USAF CE. There were no invalid R tests for men or women. There were no invalid RSS tests for women, but in one test for men the HR during the 6th minute of steady-state was 2 bpm above 85% of estimated HR_{max}. While the R or RSS protocols probably would not result in a major improvement in accuracy over the current USAF CE, they should result in fewer invalid tests.

The failure to develop a significantly better test is not surprising. For the past 40 years, numerous investigators have attempted and failed to develop a better submax test and tried to deal with the problems inherent in estimating VO_{2max} from a submaximal protocol. It appears that the use of $\dot{V}_E$ could improve the estimation of VO_{2max} slightly, but even if the measurement of V_E was economically feasible, the reliability of the equipment and technicians would need to be investigated. Since the RSS equations tend to do better than the R equations, it may be worthwhile to have CDSI apply their more sophisticated statistical program and analysis to the RSS data.

The one-mile walk equation produced values that were as good as or better than the other equations. This was true for men and women for the entire sample or when limiting the sample to the younger subjects. Since Dolgener et al (7) had found such low correlation coefficients with college-age subjects, it was important to look specifically at that age group.

The results from the current study and those of Kline et al. (17) are very similar, so a comprehensive cross-validation is not needed. However, there are some potential logistical advantages and disadvantages to a one-mile walk that need further study, analysis and discussion before it can be used with selected USAF units. Among the potential logistical problems are varying environmental and physical conditions. This study was conducted in a controlled environment. Heat, cold, wind, rain, and humidity could all affect the HR and the time to walk one mile. These factors could be controlled by conducting the test in a gymnasium, but inaccurate distance measurements, tighter turns and the different surfaces of a gymnasium could affect the estimated VO_{2max}. Another potential logistical problem is how many subjects would exceed 85% of their estimated HR_{max} and how this would be handled. (Sixteen percent of the subjects in the current study exceeded 85% of their estimated HR_{max} during the one-mile walk test. Their data was included in the analysis.) Also, there will be some heart watch failure during the one-mile walk. This happens during laboratory testing also, but is recognized (and usually fixed) immediately. Heart watch failure during the one-mile walk test would not generally be recognized until the end of the test or until it is downloaded into the computer. All of these factors will need to be investigated thoroughly to help determine whether the one-mile walk test is a viable test for the USAF.

Recommendations

1. Have CDSI develop equations with the RSS data.
2. Add the Phase 1 and 2 data together and re-develop the equations.
3. Conduct a cross-validation of the R and RSS similar to the cross-validation conducted by Pollock et al. (22) on the current USAF CE.
4. Conduct specific evaluations of the one-mile walk.

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Appendix A

Informed Consent

July 10, 1997

THE UNIVERSITY OF TEXAS AT AUSTIN

Department of Kinesiology and Health Education

Consent Form for Participation in a Study Examining

SUBMAXIMAL AEROBIC FITNESS EVALUATION

You are invited to participate in a study entitled **Submaximal Aerobic Fitness Evaluation**. The purpose of this study is to provide an alternate submaximal cycle ergometry test protocol designed to significantly increase both the accuracy and reproducibility of the United States Air Force's (USAF) current submaximal exercise test to estimate aerobic endurance capacity. The subjects for this study will include up to 60 healthy men and 60 healthy women (i.e., healthy = free of chronic degenerative diseases, such as uncontrolled hypertension, heart disease and uncontrolled diabetes) between 18 and 49 years of age. Your meeting these requirements makes you eligible for participation in this study, and this is why you are being invited to participate.

If you elect to participate in this study you will be tested to the point of maximal effort twice on separate days on either 1) a cycle ergometer and a treadmill or 2) twice on the treadmill_to determine your maximal oxygen uptake (our best estimate of your cardiovascular endurance). During these two tests you will be monitored for heart rate, and the amount of oxygen you use will be measured using the SensorMedics metabolic measurement cart (MMC). Data from these two initial maximal tests will be used as the absolute measure of your aerobic capacity. You will also complete up to three submaximal exercise tests on separate days using several protocols. These submaximal tests will allow us to determine the reproducibility of submaximal testing, and will allow us to determine how accurately these submaximal protocols estimate your true aerobic capacity. You will be tested at the same time of day under exactly the same conditions to reduce variability in your responses to exercise.

There are few potential risks associated with your participation in this study. The risks associated with maximal and submaximal exercise testing are minimal, with subject discomfort at the higher levels of exercise being the most common complaint. Further, there is the remote possibility of heart rhythm disturbances, dizziness or fainting, musculoskeletal injury, and an extremely remote chance of heart attack during the exercise testing or training sessions. These risks, however, are most unusual, and generally are observed only in an older, high risk population. Your heart rate will be monitored by an exercise physiologist during all submaximal tests, and your heart rate, ventilation and oxygen consumption will be monitored by an exercise physiologist during all maximal tests to reduce the risk of any possible event or injury. For any male 40 years of age and older, a physician will be present to monitor the maximal exercise tests, and a 12-lead electrocardiogram will be obtained at rest and during exercise. Women are considered at lower risk and physician supervision is not necessary until 50 years of age (American College of Sports Medicine).

In the unlikely event of injury resulting from any of the above stated procedures, emergency treatment will be rendered by attending technicians who are trained and certified in CPR. Further care and follow-up will be provided at the nearest hospital if necessary. You will not receive compensation for wages, lost time, medical expenses, or hospitalization. For your involvement in this study, completing all aspects of the study, you will receive $50. The principal investigator for this study is Jack H. Wilmore. If you have any further questions you may contact him at Bellmont Hall 222 (471-4405) during normal business hours, or at 409-695-8553 in the evenings and on weekends. If you have any questions regarding your rights as a participant, please contact Mr. Frank Hood, Chair of the Human Subjects Committee for Battelle, the primary contractor for this project. He can be reached at the following numbers: phone - 614-424-4181; fax - 614-424-6587; or at the following address: Battelle, 505 King Avenue, Columbus Ohio 43201. Data compiled from your performance will be kept in strict confidence at all times. Only the principal investigator, graduate students working on this project, and USAF scientists will have access to this information. Data files will be kept in a locked filing cabinet for the life of the data, after which all data will be destroyed.

Your signature below indicates that you have decided to participate in this study and that you have read and understand the information in this consent form. Your decision to participate in this study will not affect your relationship, present or future, with this university. If you decide to participate, you are free to withdraw consent and discontinue participation at any time. A copy of this consent form will be given to you for future reference. All of your questions have been answered to your satisfaction and any additional questions arising from participation in this study will be answered by the principal investigator or his representatives.

Participant's Signature ______________________________ Date: ______________________

Principal Investigator ______________________________ Date: ______________________

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Appendix B

Cycle Ergometry Protocol Worksheets

Banister-Legge Submax-to-Max Worksheet

NAME: ________________ Date: _______________ Time: ________________

Seat Hgt.: _____ Weight: ___ PHR max: ___________ 85% PHR max: __________

Time	**Speed/Grade**	**Heart Rate**	**Comments**
0 -1	Rest		
1- 2	Rest		
0-1	Unloaded		
1-2	Unloaded		
2-3	Unloaded		
3-4	Unloaded		
4-5	Unloaded		
5-6	50 W		
6-7	50 W		
7-8	50 W		
8-9	100 W		
9-10	100 W		
10-11	100 W		
11-12			
12-13			
13-14			
14-15			
15-16			
16-17			
17-18			
18-19			
19-20			
20-21			
21-22			
22-23			
0-1	Rec-Unload		
1-2	Rec-Unload		
2-3	Rec-Unload		

Ramp Steady-State Worksheet **MEN**

NAME: ________________ Date: ______________ Time: ______________

Seat Hgt.: _____ Weight: ___ PHR max: __________ 70% PHR max: __________

Time	Workrate	Heart Rate	Comments
0 -1	Rest		
1- 2	Rest		
0-1	Unload		
1-2	Unload		
2-3	Unload		
3:00-3:20	50		
3:20-3:40	55		
3:40-4:00	60		
4:00-4:20	65		
4:20-4:40	70		
4:40-5:00	75		
5:00-5:20	80		
5:20-5:40	85		
5:40-6:00	90		
6:00-6:20	95		
6:20-6:40	100		
6:40-7:00	105		
7:00-7:20	110		
7:20-7:40	115		
7:40-8:00	120		
8:00-8:20	125		
8:20-8:40	130		
8:40-9:00	135		
9:00-9:20	140		
9:20-9:40	145		
9:40-10:00	150		
10:00-10:20	155		
10:20-10:40	160		
10:40-11:00	165		
11:00-11:20	170		
11:20-11:40	175		
11:40-12:00	180		
12:00-12:20	185		
12:20-12:40	190		
12:40-13:00	195		
13:00-13:20	200		
13:20-13:40	205		
SS 0-1			
SS 1-2			
SS 2-3			
SS 3-4			
SS 4-5			
SS 5-6			
0-1	Recovery-20		
1-2	Recovery-20		
2-3	Recovery-20		

Ramp Steady-State Worksheet **WOMEN**

NAME: ____________________ Date: ________________ Time: ______________

Seat Hgt.: _____ Weight: _____ PHR max: _____________ 70% PHR max: ______

Time	Workrate	Heart Rate	Comments
0-1	Rest		
1-2	Rest		
0-1	Unload		
1-2	Unload		
2-3	Unload		
3:00-3:20	25		
3:20-3:40	30		
3:40-4:00	35		
4:00-4:20	40		
4:20-4:40	45		
4:40-5:00	50		
5:00-5:20	55		
5:20-5:40	60		
5:40-6:00	65		
6:00-6:20	70		
6:20-6:40	75		
6:40-7:00	80		
700-7:20	85		
7:20-7:40	90		
7:40-8:00	95		
8:00-8:20	100		
8:20-8:40	105		
8:40-9:00	110		
9:00-9:20	115		
9:20-9:40	120		
9:40-10:00	125		
10:00-10:20	130		
10:20-10:40	135		
10:40-11:00	140		
11:00-11:20	145		
SS 0-1			
SS 1-2			
SS 2-3			
SS 3-4			
SS 4-5			
SS 5-6			
0-1	Recovery-20		
1-2	Recovery-20		
2-3	Recovery-20		

Ramp Ergometer Worksheet **MEN**

NAME: ________________Date_______________ Time: _______________

Seat Hgt. _____ Weight: ___ PHR max: ___________ 85% PHR max: __________

Time	Workrate	Heart Rate	Comments
0 -1	Rest		
1- 2	Rest		
0-1	Unload		
1-2	Unload		
2-3	Unload		
3:00-3:20	50		
3:20-3:40	55		
3:40-4:00	60		
4:00-4:20	65		
4:20-4:40	70		
4:40-5:00	75		
5:00-5:20	80		
5:20-5:40	85		
5:40-6:00	90		
6:00-6:20	95		
6:20-6:40	100		
6:40-7:00	105		
7:00-7:20	110		
7:20-7:40	115		
7:40-8:00	120		
8:00-8:20	125		
8:20-8:40	130		
8:40-9:00	135		
9:00-9:20	140		
9:20-9:40	145		
9:40-10:00	150		
10:00-10:20	155		
10:20-10:40	160		
10:40-11:00	165		
11:00-11:20	170		
11:20-11:40	175		
11:40-12:00	180		
12:00-12:20	185		
12:20-12:40	190		
12:40-13:00	195		
13:00-13:20	200		
13:20-13:40	205		
13:40-14:00	210		
14:00-14:20	215		
14:20-14:40	220		
14:40-15:00	225		
15:00-15:20	230		
15:20-15:40	235		
0-1	Recovery-20		
1-2	Recovery-20		
2-3	Recovery-20		

Ramp Ergometer Worksheet **WOMEN**

NAME: ____________________ Date: ________________ Time: ______________

Seat Hgt. _____ Weight: _____ PHR max: ____________ 85% PHR max: ______

Time	Workrate	Heart Rate	Comments
0-1	Rest		
1-2	Rest		
0-1	Unload		
1-2	Unload		
2-3	Unload		
3:00-3:20	25		
3:20-3:40	30		
3:40-4:00	35		
4:00-4:20	40		
4:20-4:40	45		
4:40-5:00	50		
5:00-5:20	55		
5:20-5:40	60		
5:40-6:00	65		
6:00-6:20	70		
6:20-6:40	75		
6:40-7:00	80		
7:00-7:20	85		
7:20-7:40	90		
7:40-8:00	95		
8:00-8:20	100		
8:20-8:40	105		
8:40-9:00	110		
9:00-9:20	115		
9:20-9:40	120		
9:40-10:00	125		
10:00-10:20	130		
10:20-10:40	135		
10:40-11:00	140		
11:00-11:20	145		
11:20-11:40	150		
11:40-12:00	155		
12:00-12:20	160		
12:20-12:40	165		
12:40-13:00	170		
0-1	Recovery-20		
1-2	Recovery-20		
2-3	Recovery-20		

Appendix C
Questionnaire Forms

The University of Texas
Human Performance Lab

USAF Submaximal Cycle Ergometry Study:
Pre-Evaluation Questionnaire

		Yes	No
1).	Are you pregnant?	____	____
2).	Do you have any physical limitations that would prevent you from riding a stationary bike or running on a treadmill properly?	____	____
3).	Have you recently been ill or injured?	____	____
4).	Have you donated blood or have you lost an equivalent amount of blood from injury with the past 30 days?	____	____
5).	Has your doctor ever said that you have a heart condition and that you should only do physical activity recommended by a doctor?	____	____
6).	Do you feel pain in your chest when you do physical activity?	____	____
7).	In the past month, have you had chest pain when you were not doing physical activity?	____	____
8).	Do you lose your balance because of dizziness or do you ever lose consciousness?	____	____
9).	Do you have a bone or joint problem that could be made worse by a change in your physical activity?	____	____
10).	Is your doctor currently prescribing drugs (for example, water pills) for your blood pressure or heart condition?	____	____
11).	Do you know of any other reason why you should not do physical activity?	____	____

12). How often do you exercise aerobically (walking, running, cycling, stair-stepping, etc.) for 30 minutes or more per week?

____0 times

____1-2 times

____3 or more times

Please sign and date below.

______________________________ ______________

Signature Date

The University of Texas
Human Performance Lab

USAF Submaximal Cycle Ergometry Study:
Daily Questionnaire

Name: ______________________________ Date: ________________

		Yes	No
1).	Have you eaten or had any caffeine, nicotine, or decongestants in the past 3 hours?	____	____
2).	Have you performed any strenuous activity in the past 12 hours?	____	____
3).	Have you had alcohol within the past 10 hours?	____	____
4).	Have you taken any medications, including aspirin, in the last 12 hours? If yes, please list__________________________	____	____

5). How much sleep did you get last night? ________hours.

6). How much sleep do you normally get per night? __________hours.

7). How do you feel today?

_____Excellent _____Very good _____Good

_____Neither good nor bad _____Bad _____Very bad

_____Terrible